Smart Grid ICT infrastructure: New Zealand perspective

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Abstract

In the transition of power system industry from traditional electricity grid towards Smart grid the distribution utilities are facing increased expectation from variety of stakeholders to support national energy efficiency and climate change policy targets. In this context, the leverage of ICT infrastructure in New Zealand is a vital requirement. The various pilot projects being implemented worldwide show that there are many smart grid communication solutions. To investigate leveraging of New Zealand ICT it is required that the advancement of the existing international Information and Communication Technology (ICT) to be fully understood. It is also required that a complete picture of the existing ICT practices and their applications used by the country distribution utilities to be presented and to be compared to the practices followed by the other countries. This may lead to development of new ICT applications for New Zealand emerging Smart Grid. This paper addresses the different technologies and opportunities of Smart Grid communications infrastructure used worldwide and the focus is mainly on the types of communication networks which are classified into premises, field area and wide area networks. Finally, the applied/planned communication technologies in New Zealand are compared with the practices followed by the rest of the world and consolidation of smart grid applications in terms of New Zealand perspective along with its best fit communication technology is addressed in the paper.

1. Introduction

The electrical grid refers to the interconnected power system network, which transfers power from all participating generators to consumers spread throughout. It has undergone several changes since its inception. The emerging grid is expected to make use of the advanced technologies from Information and Communication Technology (ICT) to gather the information from across its various participants. The information gathered from different stakeholders would be used to control and monitor in order to improve the efficiency, reliability, flexibility and for economic benefits. There has to be a real-time coordination between the stakeholders in the electricity sector, which could be achieved by properly using the ICTs in the smarter grid [1] [2].

2. Smart Grid Communication

The different stakeholders/participants in the power system industry are Generators, Transmission, Distribution, Retailers, Electricity markets and Electricity consumers. With Smart Grid in place, all these stakeholders can interact with each other using different communication technologies. A Smart Grid has different layers which enables the interaction between different stakeholders and is pictorially shown in Figure 1 [3].

<table>
<tr><td colspan="5">Smart Metering and Grid Applications</td><td colspan="3">Customer Applications</td><td>Application Layer</td></tr>
<tr><td colspan="8">Authentication, Access Control, Integrity Protection, Encryption, Privacy</td><td>Security Layer</td></tr>
<tr><td colspan="3">Cellular, WiMax, Fiber Optic</td><td colspan="2">PLC, DSL, Coaxial Cable,RF Mesh</td><td colspan="3">Home Plug, ZigBee, WiFI, Z-Wave</td><td rowspan="2">Communication Layer</td></tr>
<tr><td colspan="3">WAN</td><td colspan="2">NAN / FAN</td><td colspan="3">HAN / BAN / IAN</td></tr>
<tr><td>PMUs</td><td>Cap Banks</td><td>Reclosure</td><td>Switches</td><td>Sensors</td><td>Transformers</td><td>Meters</td><td>Storage</td><td>Power Control Layer</td></tr>
<tr><td colspan="3">Power transmission / Generation</td><td colspan="2">Power Distribution</td><td colspan="3">Customer</td><td>Power System Layer</td></tr>
</table>

Figure 1: System Architecture of Smart Grid [3]

As shown in the Figure 1, the Power System layer represents the main functions of power system. Power control layer shows the different elements which are used to monitor and control the power system. Communication layer enables the communication between stakeholders using different communication technologies available. Security layer provides the data confidentiality, integrity, authentication and availability. Application layer provides different Smart Grid applications to its stakeholders [3] [4].

The communication network architecture which connects all the stakeholders together is pictorially represented in Figure 2. The overall architecture can be divided into three main network areas as Premises Network, Neighbourhood / Field Area Network (NAN / FAN) and Wide Area Network (WAN).

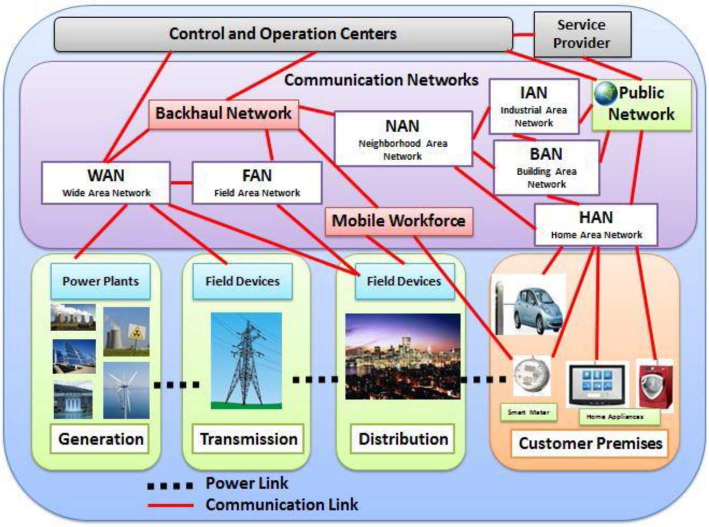

Figure 2: Communication networks for Smart Grid [5]

Premises Network provides communication access for consumer devices, which will enable them to interface with smart grid. Premises Network is further divided into Home Area Network (HAN), Business Area Network (BAN) and Industrial Area Network (IAN).

Neighbourhood Area Network would cater the communication link between Smart or Advanced meters at a neighbourhood level or devices like IEDs and field level.

Wide Area Network (WAN) is the final stage of the network architecture that connects Neighbourhood Area Network to the utility. The Wide Area Network has three main sub-networks such as Backbone Network, Metropolitan Area Network (MAN) and the Backhaul Network.

The data rate and communication range requirements for smart grid communications architecture is pictorially represented in Figure 3 [3].

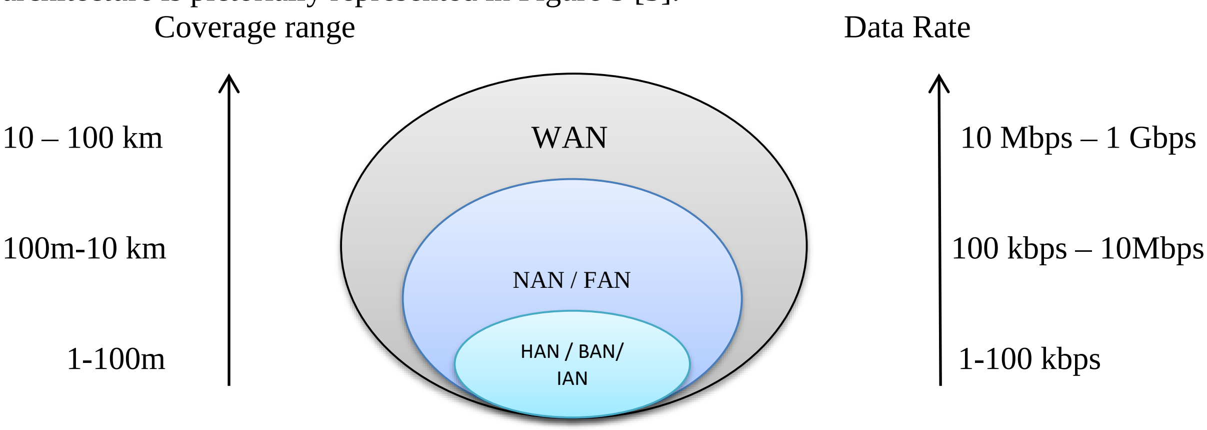

Figure 3: Date rate & communication range requirements for smart grid communications [3]

2.1 Wireless Communication Technologies

Wireless communication is considered as one of the fastest growing sectors in communication industry. The positioning of wireless nodes can be flexible and located as per the requirements and reach. With the help of this flexibility, wireless communication could reach the places which are cumbersome for wired communication to reach [4]. With this advantage, Wireless communication is getting popular. This section would explain the available Wireless communication technologies.

2.1.1 Z-Wave

Z-Wave was initially developed by Zensys Inc and later it was acquired by Sigma Designs in 2008 [4, 6]. Z- Wave makes use of ITU-T G.9959 rPHY/MAC with protocol stack from Sigma Designs and uses low power sub 1 GHz RF and works within a mesh topology. The mesh topology of Z-Wave enables each device within a Z-Wave network to relay signals to other devices which makes network to be extended easily. 232 nodes (Z-Wave devices) can be connected to a Z-Wave hub [7]. Z- Wave offered a low data rate of 9.6 kbps. Later, it was extended to 40 kbps. Z-Wave 400 series also supports 2.4 GHz band and 200 kbps data rate. Its reach is limited to 30m indoor and could extend up to 100m in outdoor [8]. It currently utilizes 921.4 MHz band in New Zealand [9].

2.1.2 Bluetooth

Bluetooth technology was initially developed by Ericson during 1994. Later, Bluetooth Special Interest group (SIG), Inc., was founded during 1998, to maintain and enhance the technology [8, 10]. Bluetooth follows IEEE 802.15.1 and does not have a meshed network like other wireless technologies. Bluetooth uses 2.4 GHz spectrum and it can transmit data at a speed of approximately 1 Mbps with a reach up to 100m [11]. “Pairing” of two devices and establishing communication between them is very easy in Bluetooth. The advantage of Bluetooth is that most of the computers and smart phones have the feature of Bluetooth and can communicate which makes it easy to integrate the controls to HAN with the devices that are already in use [11].

2.1.3 ZigBee

ZigBee is low power, two-way wireless communication standard developed by ZigBee Alliance, based on IEEE 802.15.4 standard. ZigBee offers 250kbps data rate at 2.4 GHz (16 Channels), 40 kbps per channel at 915 MHz (10 Channels) and 20 kbps at 868 MHz (1 channel). Transmission reach can vary from 10 m to 100 m which depends on power output and environmental characteristics [12]. ZigBee has a wireless mesh network in which multiple links connect each node and connections are dynamically updated and optimized. ZigBee meshed networks are de-centralized and each node has the capability to manage itself in dynamic conditions and has the ability to self-route and establish connection with new nodes as per requirement [8].

2.1.4 WiMax

WiMax (Worldwide Inter-operability for Microwave Access technology) is a mode of wireless communication medium under IEEE 802.16. WiMax uses 2.5 GHz spectrum, which makes it less prone to interference from other sources and wireless devices [11]. The maximum theoretical data rate for WiMax is 75 Mbps and could reach up to 100 km [3] [5]. WiMAX also offers flexible broadband links and low latency (10-50ms). The bandwidth, flexibility and the range of WiMAX provide an acceptable substitute for last-mile access in comparison to the traditional cable, DSL and T1 communication channels. As WiMAX was initially intended for Wireless Metropolitan Area Networks (WMANs); it is therefore one of the promising solutions for Smart Grid NANs or WANs [4].

2.1.5 Wireless Mesh Network

Wireless mesh network is one of the easily deployable and cheaper communication technologies which can cover larger area. Wireless mesh network is the accumulation of mutually supportive wireless access points which can be arranged in such a manner to allow multiple paths back to a physical location, which is either a wired network or wireless hotspot. Wireless mesh networks are based on 802.11 protocols with the addition of some means of routing control [11]. Wireless mesh network has two major categories such as Broadband Wireless Mesh and Narrowband Radio Frequency (RF) Mesh [13].

2.1.6 Cellular

Available communication technologies under cellular communication are 2G, 2.5G, 3G, 3.5G and 4G. Initially this technology was designed to support mobile communication services in 1980s. With the evolution of 2.5G standards such as GPRS and EDGE, transmission of data by cellular networks was made possible. However, 3G and 4G mobile technologies now enable higher data rates and roaming capabilities. This presents the opportunity to use cellular technologies as a communication methodology in the Smart Grid vision [4]. Data rates for different cellular technologies are 2G -14.4 kbps, 2.5G -144 kbps,3G- 2 Mbps, 3.5G- 14 Mbps, 4G - 100 Mbps. These cellular technologies have coverage up to 50 km [3].

2.1.7 Cognitive Radio Networks

Cognitive radio technology is a stand-alone radio based on IEEE 802.22 and enables the secondary users to access the spectrum when it is not used by the primary licensed user efficiently without causing any interference with primary users. This spectrum sensing technique could be widely deployed in Smart Grid WAN, backhaul and distributions networks over large geographic area. Cognitive radios make the smart grid “smarter” and provide to it more security, scalability, robustness, reliability and sustainability [5].

2.1.8 DASH7

Dash 7 is a technology for wireless sensors networks based on ISO/IEC 18000-7 standard and promoted by Dash 7 Alliance. It operates at a 28 kbps rate up to 200 kbps and it has coverage of about 250 m extendable to 5 km. The dash 7 uses very small amount of energy for wake up signal up to 30-60 mW and it is low latency with around 2.5-5 s. It is widely deployed for military application and also commercial applications such building automation, smart energy, smart home, PHEVs, logistics control and monitoring. Dash 7 seems to be a suitable alternative to ZigBee [5].

2.2 Wired Communication

Wired communication is a communication technology in which data is transmitted through the lines or cables. This technology requires the physical interconnection between two nodes to enable the data transfer between the nodes. Due to this requirement, wired communication is expensive compared to the wireless communication. However, wired communication offers higher data transmission rates and shorter delay compared to wireless communication. This section would address the different technologies in wired.

2.2.1 Fibre- Optic

Fibre-Optic is one of the leading and much talked wired communication technologies. Fibre-optic system consists of a transmitting device which converts an electrical signal into a light signal. This light signal is transmitted through the fibre-optic cable and finally the light signal is converted back to electrical signal. Fibre optic has many advantages over metallic based communications such as long distance signal transmission, larger bandwidth, light weight, non-conductivity and security [14]. Optical fibre networks differ based on the network topology and the technology used; such as PON (Passive Optical Network: 155 Mbps-2.5Gbps), WDM (Wavelength Division Multiplexing: 40Gbps) and SONET (Synchronous Optical Network: 10Gbps) [3].

2.2.2 DSL

Digital Subscriber Line (DSL) uses telephone lines for transferring the data. It is a high speed connection to internet that utilizes the twisted-pair copper wires which is mainly used to carry telephone signals. These pair of copper wires has the necessary required bandwidth to carry both data and voice. Since voice signals uses only a fraction of available bandwidth, data transfer through DSL can be maximized by utilizing the available bandwidth [4]. DSL includes a series of technologies such as HDSL (High bit-rate DSL), SDSL (Symmetric DSL), ISDN DSL (Integrated Services Digital Network DSL), RADSL (Rate Adaptive DSL), ADSL (Asymmetric DSL) and VDSL (Very high bit-rate DSL) [4].

2.2.3 Power Line Communication (PLC)

Power Line Communication (PLC) uses power lines as a communication channel for transmission of data. With the advantage of widespread availability of the electrical infrastructure, PLC reduces the deployment costs compared to other wired solutions as the only additional cost originates from deploying new modems to the electric grid. However, data signals cannot propagate through transformers and hence the power line communication is limited between transformers. It is considered to be suitable solution for Premises Networks, NANs and FANs. It can also operate over high voltage lines as well [4]. PLC technologies can be further classified into narrowband PLC (NB-PLC) and broadband PLC (BB-PLC). NB-PLC is known to operate usually below 500 kHz and BB-PLC is known to operate at frequencies about 1.8MHz. Some broadband PLC systems operate in the 230MHz band and can achieve data rates up to 200Mbps. Three PLC standards possibly used in the Smart Grid vision are IEEE P1901, ITU-T G.hn, and ANSI/CEA 709[4].

2.3 Suitability of Communication Technologies for different applications

It is noted that the communication technologies used by the utilities are differing mainly due to the availability of wide range of communication technologies and based on the utilities requirements. The major available wired communication technologies that can be used for Smart Grid are copper pair communication, Power Line Communication and Optical Fibre communication. Out of these, PLC communication can be implemented at low cost considering the fact that the infrastructure is already available. PLC could be a best fit for HAN and NAN (up to 3 km) [3] [20]. Optical fibre communication can be used in different topologies and it is mostly preferred for longer distances and for WAN [3]. Similarly wireless communications can be used for HAN, NAN and WAN based on their data rate and coverage area. Summary of communication technologies with advantages and disadvantages are tabulated in Table 1.

Table 1: Summary of communication technologies for Smart Grid [5]

Family	Coverage	Application	Advantages	Disadvantages
PLC	NB-PLC: 150 km BB-PLC: 1.5 km	NB-PLC: AMI, FAN, WAN BB-PLC: HAN/AMI	Communication infrastructure is already established, Low cost, Separation from other communication networks	Non-interoperable ; High signal attenuation; Channel distortion; Interference with electric appliances and electromagnetic sources; High bit rates difficulties; Complex routing
Fiber	Between 10 km and 60 km depends on standard used	WAN AMI	Very Long-distance Ultra-high bandwidth Robustness against interference	High costs; Difficult to upgrade; Not suitable for metering applications
DSL	Between 300 m and 7 km depends on the variant used	AMI FAN	Commonly deployed for residential users Infrastructure is already established	High prices to use Telco networks Not suitable for long distances
WiFi	Between 300 m outdoors and up to 1 km depending on versions	V2G HAN AMI	Low-cost network deployment and equipment's flexibility Has several use cases	High interference; High power consumption; Simple QoS support;
WiMAX	Between 10 km and 100 km depends on performance	AMI FAN WAN	Suitable for high range of simultaneous Longer distances comparing with WiFi Connection-oriented	Complex Network management High cost of terminal equipment Licensed spectrum use

Family	Coverage	Application	Advantages	Disadvantages
			Sophisticated QoS	
3G GSM, GPRS, EDGE	HSPA+: 0–5 km	V2G HAN AMI	Supports millions of devices; Low power consumption; Cellular SG specific service solutions; High flexibility, suitable for Different use cases; Licensed spectrum use reduces interference; Open industry standards;	Could have High prices for the use of Telco Operators networks Licensed spectrum use Latency
4G LTE/LTE-A	0–5 km up to –100 km (impacting performance)	V2G HAN AMI	Same as 3G with higher flexibility, enhanced technology, and handover	Latency High cost
ZigBee	Up to 100m	V2G HAN AMI	New ZigBee SEP 2.0 standards with full interoperability with IPv6 based networks	Low bandwidth Not suitable for large networks
Cognitive Radio	Up to 100 Km	AMI WAN	Very long distances; High performance; Scalable; Fault tolerant broadband access; Reliability;	Interference with licensed users
Dash7	Typical range about 250 m extendable to 5 km	V2G HAN AMI	Low cost; Low power; Lower range than ZigBee; Efficiency	Not suitable for large networks

3. Existing / Proposed NZ practise

The New Zealand electricity sector is in the transition stage from traditional grid towards Smart Grid. There are many different communication technologies are being used in the traditional grid for SCADA communication, monitoring and control. Further, advanced communication links are being established as part of Smart Grid. This section covers the different communication links that are currently being used or under implementation stage in New Zealand.

3.1 Communication technologies used by distribution utilities

Almost all the distribution companies use radio links for voice and data communications. Commonly used radio links are VHF, UHF and Microwave radio links. Out of three, VHF and UHF are being used throughout New Zealand. Seven distribution companies (approximately 24%) are using Microwave radio links in addition to VHF and UHF. Where there are gaps in radio network, cellular communications such as 3G / GPRS are used. Further, 10 distribution companies (approximately 34%) are using copper cables for communication [1]. The existing communication technologies used in NZ by different distribution companies are pictorially shown in Figure 4.

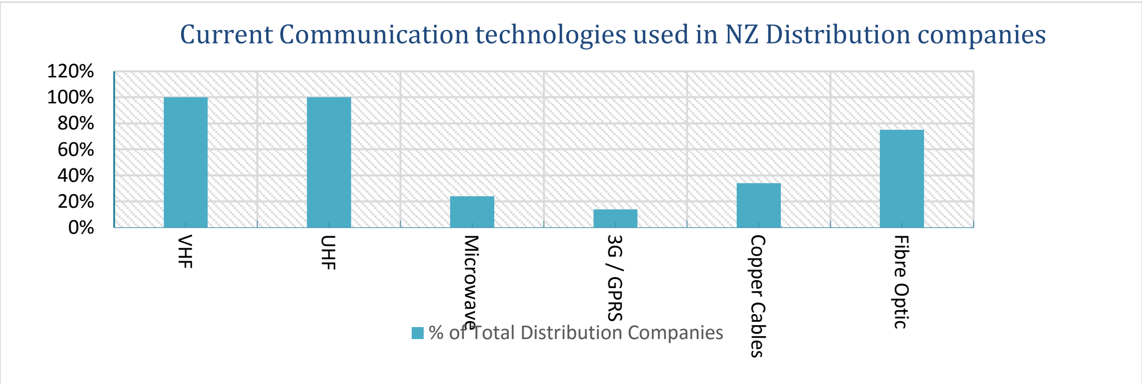

Figure 4: Communication technologies used in NZ distribution companies

It is noted that the communication technologies such as VHF, UHF, Microwave radio links and copper cables have played a vital role serving as communication medium in the traditional electric grid in New Zealand. Most of the distribution companies are upgrading to fibre-optic (own links) [1].

3.2 Usage of Fibre optic

Most of the distribution companies in New Zealand have their own fibre-optic and/or are using leased fibre-optic. It is observed that, out of 29 distribution companies,

- 22 distribution companies (Around 75% of companies) are using Optical fibre cable as one of their communication links.
- 7 distribution companies (Around 25% of companies) have minimum or no Optical fibre cable in their network.

It is noted that, Fibre-optic is connected to most of the major zone substations in these distribution companies and it has been mainly used for SCADA communication (either Primary or as backup) and protection signalling [1]. Further as per the government objective, 75 % of the New Zealand population should have the Ultrafast Broadband by 2019 which is also known as Fibre to the Premises network. This project covers 33 largest towns and cities in New Zealand. The network which is being deployed is known as GPON topology. GPON is a point to multipoint, fibre to the premises network architecture with a single optic fibre cable which is capable of providing service to multiple users. Splitters used in GPON, divide the signal from exchange normally between 32 and 64 individual houses and business units. This GPON technology can be used for both voice and broadband services. The project offers services of at least 100 Mbps downstream and 50 Mbps upstream. The upstream speed available which is minimum of 10 Mbps is much higher than that of currently used ADSL2+ copper broadband products in New Zealand [18] [19]. Hence Fibre-Optic could be one of the solutions for WAN part of Smart grid communication.

3.3 Communication between HAN and NAN

As part of the Advanced Metering Infrastructure, smart meters are being rolled out in New Zealand. Around 52% of the ICPs in New Zealand have smart meters. Majority of the meters are being supplied by four main meter equipment and service providers (AMS, Metrix, Arc Innovations and SmartCo) [21]. The smart meters installed require communication medium for data and information exchange. Hence, in addition to the rollout of smart meters, the communication medium required for smart meters is also being implemented. The smart meters installed in New Zealand can communicate using different communication technologies which are as follows.

- General Packet Radio Service (GPRS): Cellular transmission in 900MHz or 1800MHz frequency bands. It is a point-to-point communication from the smart meter to a cell phone tower, OR,
- Radio Mesh: Radio transmission in the 900MHz frequency band – a point-to-many communication. These systems are relatively low power with a short range of a few kilometres. Information is collected into data concentration points and relayed [1].

It is noted that, Radio mesh network is being implemented in most of the distribution companies in New Zealand for communicating with smart meters. Rest of the distribution companies use GPRS for communication [1].

4. Comparison of Practices

Due to the availability of wide range of communication technologies, different technologies have been used globally. This section covers the international practices and compares it with current / future New Zealand practices. Table 2 is a consolidated presentation of the preferred

/ tested communication technologies for NAN / FAN in various countries. In general, PLC is the preferred communication technology for NAN / FAN in most of the European countries except UK. UK has used GPRS during pilots and prefers either Radio Frequency mesh or GPRS for complete roll out. Wireless communication technologies like RF Mesh network are preferred communication links for NAN / FAN in USA [3]. WiMax has widely been deployed in Victoria Australia by SP Ausnet. Long Term Evolution (LTE) is in limited deployment in private utility networks including Ausgrid and a partnership between Green Mountain Power and Vermont Telephone Company in USA; however it is gaining traction as the first global cellular standard because of its performance characteristics and support for IP. [23]. Fibre optic / WiMax is the commonly chosen technology for WAN, since it is reliable and offers high performance [3].

Table 2: Preferred / tested communication technologies from various countries [22] [23]

Country	PLC	GPRS	RF Mesh	WiMax
Germany	✓ (Preferred)	✓		
Netherland	✓			
Sweden	✓ (Preferred)	✓		
Denmark	✓ (Preferred)	✓		
Finland	✓ (Preferred)	✓		
France	✓			
Spain	✓			
UK		✓	✓	
USA			✓	
Victoria, Australia				✓

Compared to worldwide practices, it is noted that, Radio mesh network and GPRS are the main communication technologies that are being implemented / preferred in New Zealand distribution network for NAN and FAN applications. It is also observed that the Radio mesh is preferred by most of the distribution companies whereas a part of the network uses / plans to use GPRS for communication [1]. In view of the current infrastructure, future plan of distribution companies and the mass rollout of fibre-optic by the Government of New Zealand shows that the future communication medium for WAN would mainly be Fibre optic and Cellular communications.

5. Smart grid applications

As mentioned earlier, Smart Grid Communication infrastructure is classified into Premises Area Network, Neighbourhood Area Network and Wide Area Network. Each network has its own range and set of suitable communication technologies to operate with. This section initially addresses the applications based on the type of the network and then addresses the communication requirement for protection applications.

5.1 Premises Area Network applications

Smart meter plays a vital role in Premises area network. The household appliances in HAN are capable of sending and receiving signals from the smart meters, in-home displays (IHDs) and/or home energy management systems. The premises area network is connected to utility through smart meter. With the help of communication link between customers and NAN / FAN (utility), utility can perform NAN / FAN applications in residential, commercial and industrial premises. Typical NAN / FAN applications in terms of data sizes, data sampling requirements and latency requirements are explained in Table 3 [3].

5.2 Neighbourhood Area Network applications

Neighbourhood Area Network provides the platform for information exchange between HAN and utility (WAN). NAN includes a metering network (Smart meter and communication links), which is a part of AMI. It allows electricity usage information to be transmitted from Smart meters to utility and allows field devices to be controlled remotely. Typical NAN / FAN applications in terms of data sizes, data sampling requirements and latency requirements are explained in Table 3 [3].

Table 3: Summary of Smart grid applications [3]

Application	Typical data size (bytes)	Typical data sampling requirement	Latency	Communication technologies
Premises Area Network				
1) Home automation	10-100	Once every configurable period	Seconds	Wireline: PLC, Ethernet; Wireless : Z-Wave, Bluetooth, ZigBee, WiFi
2) Building automation	>100	Once every configurable period	Seconds	Wireline: PLC, Ethernet; Wireless : ZigBee, WiFi, Wireless mesh
Neighbourhood Area Network				
1a) Meter reading – (on-demand (from meters to utility)	100	As needed (7 am–10 pm)	< 15 s	Wireline : DSL, Coaxial cable, PLC, Ethernet; Wireless: ZigBee, Wireless Mesh, WiFi, WiMax, Cellular
1b) Meter reading – scheduled interval (from meters to AMI head end)	1600–2400	4–6 times per residential meter per day (24 x 7) 12 - 24 times per commercial/industrial meter per day	< 4 h	
1c) Meter reading – bulk transfer from AMI head end to utility)		x per day for a group of meters (6 am–6 pm)	< 1 h	
2a) Pricing-TOU (from utility to meters)	100	1 per device per price data broadcast event 4 per year (24X7)	< 1 min	
2b) Pricing-RTP (from utility to meters)	100	1 per device per price data broadcast event 6 per year (24X7)	< 1 min	
2c) Pricing-CPP (from utility to meters)	100	1 per device per price data broadcast event 2 per year (24X7)	< 1 min	
3) Electric service prepayment (from utility to customers)	50-150	25 times per prepay meter per month (7 am–10 pm)	<30s	
4) Demand response – DLC (from utility to customer devices)	100	1 per device per broadcast request event (24 x 7)	< 1 min	
5) Service switch operation (from utility to meters)	25	1–2 per 1000 electric meters per day (8 am–8 pm)	< 1 min	
6a) Distribution automation – (distribution system monitoring and maintenance data from field devices to DMS)	100 - 1000	CBC: 1 per device per hour (24 x 7) Feeder fault detector: 1 per device per week (24 x 7) Recloser: 1 per device per 12 h (24 X 7) Switch: 1 per device per 12 h (24 X 7) VR: 1 per device per hour (24 X 7)	< 5 s	
6b) Distribution automation – Volt/VAR control (command from DMS to field devices)	150-250	Open/close CBC: 1 per device per 12 h (24 x 7) Open/close Switch: 1 per device per week (24 x 7) Step up/down VR: 1 per device per 2 h (24 x 7)	< 5 s	
6c) Distribution automation – distribution system demand response (DSDR) (command from DMS to field devices)	150-250	Open/close CBC: 1 per device per 5 min Open/close switch: 1 per device per 12 h Step up/down VR: 1 per device per 5 min (1–6 h duration, 4–8 times a year)	< 4 s	
6d) Distribution automation – FLISR (command from DMS to field devices)	25	1 per device per isolation/reconfiguration event (<5 s, within <1.5 min of fault event)	< 5 s	
7) Outage and Restoration Management (ORM) (from meters to OMS)	25	1 per meter per power lost/ power returned event (24 x 7)	< 20 s	
8) Distribution customer storage (charge/discharge command from DAC to the storage)	25	2–6 per dispatch period per day (discharge: 5 am–9 am or 3 pm–7 pm; charge: 10 pm–5 am)	< 5 s	
9a) Electric transportation (utility sends price info to PHEV)	255	1 per PHEV per 2–4 day (7 am–10 pm)	< 15 s	
9b) Electric transportation (utility interrogates PHEV charge status)	100	2–4 per PHEV per day (7 am–10 pm)	< 15 s	
10) Premises network administration (from utility to customer devices)	25	As needed (24 x 7)	< 20 s	

5.3 Wide Area Network Applications

Wide Area Network supports the real-time monitoring, control and protection applications corresponding to the wider area i.e. utility, which can help prevent cascading outages with real-time information related to the state of the power grid. These wide area applications offer higher data resolution and shorter response time than SCADA and EMS systems. Wide area monitoring, control and protection provide high resolution data of 60 samples per second. The preferred communication technologies for WAN applications are Fibre Optic in Wireline category and WiMax and Cellular communication in Wireless communication category [3].

5.4 Protection related Smart grid application

Protective relays are basic requirement for any power system to provide quality and reliable power supply. The transition of protection relays from electro-mechanical to programmable relays took place in most of the places and now majority of the relays are programmable. The characteristics of protection relaying such as Selectivity, Sensitivity and Speed can be enhanced with availability of advanced communication technologies. Some of the relaying applications which can make use of the Smart Grid communication infrastructure are given below [24].

- Protection relay settings are based on the static configuration of the network. Relays are set such that it will be sensitive and selective under any operating conditions. Modern relays will have settings groups which can be selected based on defined set of conditions. New setting will increase the sensitivity while maintaining its selectivity. Smart Grid can help in determining the setting group scenarios and drive when to dynamically change the settings as per operating condition.
- Auto-reclosure settings are static and cannot be adjusted based on the operating scenario. By receiving real-time data, it is now possible to adjust the settings in real-time.
- As the penetration of distributed generation connected to a radial feeder increases, then Smart Grid infrastructure with the help of SIPS (System Integrity Protection Schemes) has to initiate targeted and coordinated control actions such as generation rejection, reactive power control, system separation etc. rather than tripping an entire feeder which may be counter-productive.
- Changes to Conservation Voltage Reduction settings can be produced based on real-time operating conditions. By receiving data from Smart Grid components, the required voltage levels may be obtained in an optimal manner.
- A scheme called Fault Location, Isolation and Service Restoration (FLISR) is one of the Distribution Automation (DA) tools which includes automatic sectionalizing, restoring the service by automatic circuit reconfiguration. This is achieved by coordinating operation of field services, software and dedicated communication networks to automatically determine the location of fault and rapidly reconfigure thereby changing the power flow direction so that some / all the consumers can avoid experiencing the power outages [25].

In general, in the LV network, the protection systems are required to act in less than 100ms. Considering this aspect and based on the data rate of the different communication technologies the applicable technologies to LV networks include PLC, WiMax, and public cellular data services. WiFi is also applicable if the system is cyber secured and is technically achievable through highly developed telecommunication networks.

The protection system in MV network has to act in the possible minimum time and a data rate of minimum 1Mbps is required for this. Hence, copper pair and Fiber optic from the wired technologies and WiMax and public cellular data services from wireless group are among the suitable communication technologies in MV network. VHF /UHF can be used for the distances close to the control centre located in the substation. However, IEC61850 is emerging as communication standard for the different purposes in distribution systems and it is expected that in future all distribution IEDs will be compatible to this standard.

5.5 Relay systems and Channel applications

There are some relay schemes which uses analog communications. There is a possibility of providing digital interface to such schemes using Converters and digital multiplexer or channel bank. Popular relay systems applicability with different media is explained below.

5.5.1 AC pilot wire current differential

This scheme is generally used for short line or cable protection and was popular when dedicated twisted pair copper was available for relay end to end continuous communication. Now Fibre optic current differential is a popular choice. AC pilot wire relays do not have facilities for compensating the channel delay. Based on the relaying accuracy required and the application (2 or 3 terminal), the total relay to relay delay must be less than 0.5 to 5 ms. AC pilot wire relay can be connected to digital channel bank which requires a Pilot Wire (PW) adapter (which does the required A/D conversions). It is connected to the digital system through a 56/64 kbps digital interface (DIF) module in the channel bank. Other end employs D/A and a PW adapter as well [26].

5.5.2 Phase Comparison and Current Differential

Since Phase comparison and Current differential relay schemes send phase information and current phase and magnitude information respectively, these schemes highly dependent on communication channels for proper definite zone operation. A channel delay of 1 ms creates a phase error of 21.60 and in a current differential scheme, a 1 ms delay creates a false differential current equal to about 37.5% of the though current. Hence, channel delay compensation is usually added to each relay before phase information is compared. Phase comparison or current differential relays using audio tones can communicate over digital systems using 4-wire voice frequency interfaces modules (4WIF). This method does not change the system operation in any way and the same relay system equipment can be used without replacement of any parts. The relay system reliability may increase with the use of increased reliability of fibre optics. Microprocessor-based phase comparison and current differential relays can utilize a 56 or 64 kbps direct digital interface (DIF) with the digital communications equipment. This will have an optical fibre and optical fibre interface (OFIF) option that may be useful for lengthy relay to communications equipment runs [26].

5.5.3 Directional Comparison

This scheme combines the directional and distance characteristics of an impedance relay with various pilot communication channels and provides fast tripping for faults anywhere on the line. The communication channels for directional comparison can operate over audio tone, PLC, microwave, and optical fibre. Channel delay is not as critical as for current comparison schemes, however, general coordination rules must be observed. The different channel types are integrated with the various distance elements, a number of different directional comparison schemes from the dependable direction comparison blocking (DCB) to the secure directional comparison unblocking (DCUB) schemes[26].

5.5.4 Transfer trip

These schemes use communications to provide trip information to a remote relay. The remote relay then may trip in one of the trip schemes. The available trip schemes are Direct Transfer trip (DT) – a scheme that does not need local information for a trip decision; Permissive Overreaching Transfer Trip (POTT) and Permissive Under reach Transfer Trip (PUTT) -

schemes which require a remote trip signal to permit local relay tripping. All these schemes use frequency shift audio tones over leased telephone, microwave, and fibre optics [26].

Table 1 presents the popular relay schemes with different communication channels.

Table 4: Relay systems and Channel applications [26].

Relay System type	Pilot Wire	Audio Leased Circuit	Analog Micro wave audio	Digital Micro wave audio	Digital Mux Fibre	Fibre SONET	Direct Fibre	PLC SSB (4 kHz)	Single Function PLC
Electro Mechanical Systems									
POTT	*	OK	OK	OK	OK	OK	OK	OK	OK
PUTT	*	OK	OK	OK	OK	OK	OK	OK	OK
DCB	*	OK	OK	OK	OK	NR	OK	OK	OK
DCUB	*	OK	OK	OK	OK	OK	OK	OK	OK
Phase Comparison	NO	NO	NO	NO	NO	NO	NO	NO	OK
Current Differential	OK	NR	NR	NR	**	**	OK	NR	NO
Direct transfer trip	OK	OK	OK	OK	OK	OK	OK	OK	OK
Static / Discrete systems									
POTT	*	OK	OK	OK	OK	OK	OK	OK	OK
PUTT	*	OK	OK	OK	OK	OK	OK	OK	OK
DCB	*	OK	OK	OK	OK	OK	OK	OK	OK
DCUB	*	OK	OK	OK	OK	OK	OK	OK	OK
Phase Comparison	*	OK	OK	***	***	***	OK	OK	OK
Current Differential	OK	OK	OK	***	***	***	OK	NR	NO
Direct transfer trip	OK	OK	OK	OK	OK	OK	OK	OK	OK
Micro-processor systems									
POTT	*	OK	OK	OK	OK	OK	OK	OK	OK
PUTT	*	OK	OK	OK	OK	OK	OK	OK	OK
DCB	*	OK	OK	OK	OK	OK	OK	OK	OK
DCUB	*	OK	OK	OK	OK	OK	OK	OK	OK
Phase Comparison	*	OK	OK	****	****	****	OK	***	OK
Current Differential	NR	OK	OK	****	****	****	OK	NR	NO
Direct transfer trip	NR	OK	OK	OK	OK	OK	OK	OK	OK

NR : Not recommended; ***:** Possible using audio tone; ****:** This Application Must Keep Channel Delay To A Minimum Possibly Less Than 0.5 To 5 ms ; *****:** OK Using A 4 Wire Tone Interface; ******:** OK Using A 4 Wire Tone Interface But Better To Use 64 kBps Digital Interface;

6. Future scope in New Zealand

It is evident that most of the applications listed in Table 3 could be achieved in future considering the roll out of AMI (which includes the RF Mesh / GPRS coverage) which provides the communication link between premises area network and NAN / FAN. Further, most of the distribution companies are planning to use fibre optic cables for protection signalling (especially differential protection). This would enable the meshed operation of the distribution feeders providing selective protection for each zone so that any distribution circuit fault only interrupts supply to a single zone and other zones remain energized via alternative paths [27].

7. Conclusion

This paper explores the network architecture, different communication technologies available in the industry and smart grid communication requirements for their intended applications. Communication channel requirement for protection relaying is also discussed. Further, the communications used in HAN, NAN/ FAN and WAN in New Zealand was compared with the practices followed by the rest of the world with an emphasis of NAN / FAN applications. This can be particularly useful for NZ distribution utilities.

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